COMPACT INTEGRATED COMBUSTION REACTORS, SYSTEMS AND METHODS OF CONDUCTING INTEGRATED COMBUSTION REACTIONS

RELATED APPLICATIONS

In accordance with 35 U.S.C. sect. 119(e), this application claims priority to U.S. Provisional Application No. 60/751,125 filed 16 Dec. 2005.

INTRODUCTION

Microchannel devices have generated great interest due to their reduced distances for heat and mass transport and corresponding ability for greater volumetric productivity. An early microchannel, laminated mass exchanger used an external source for heat exchange and this device is described in U.S. Pat. No. 6,533,840. Other laminated microchannel devices have employed integrated combustion to provide heat for an endothermic process in an adjacent layer.

An example of a compact alcohol steam reformer/catalytic combustor with integrated methanation is shown in a published U.S. patent application Ser. No. 2004/0223908 to Holladay et al.

Despite this and other work over many years, there remains a need for compact and efficient steam reformers, and integrated combustors with reduced hot spots.

SUMMARY OF THE INVENTION

In a first aspect, the invention provides a compact steam reformer, comprising: a reactant preheat section; a steam reforming reaction chamber comprising a steam reforming catalyst; wherein the steam reforming reaction chamber is in conductive thermal contact with the reactant preheat section such that, during operation, heat from the steam reforming reaction chamber can be conducted directly across (here, "directly across" means perpendicular to flow, not along the length of a chamber wall) a reaction chamber wall into the reactant preheat section; wherein the reactant preheat section comprises an inlet and an outlet, and wherein the reactant preheat section outlet is disposed such that, during operation, flow from the reactant preheat section outlet flows into the steam reforming reaction chamber; a combustion chamber adjacent to the steam reforming reaction chamber and separated from the steam reforming reaction chamber by a chamber wall; wherein the combustion chamber comprises a combustion catalyst; and a combustion preheat chamber; wherein the combustion chamber is in conductive thermal contact with the combustion preheat section such that, during operation, heat from the combustion chamber can be conducted through a combustion chamber wall into the combustion preheat section; wherein the combustion chamber comprises an inlet and an outlet, and wherein the combustion chamber outlet is disposed such that, during operation, flow from the combustion chamber outlet flows into the combustion preheat section. Although heat is transferred directly across a reaction chamber wall, the reformer preheat section (as well as the combustor preheat section) preferably includes several layers in which additional heat is transferred directly across a wall. An example is shown in FIG. **1**. In a preferred embodiment, this compact steam reformer further includes a methanation catalyst disposed in the reactant preheat section. Preferably, the reactant preheat section comprises: methanator, vaporizer and superheat subsections. In some embodiments, catalyst in steam reforming and/or catalyst sections are flow-by. The catalyst in any or all of the reaction sections may include a large pore catalyst. Preferably, the combustion channel has at least one dimension of 5 mm or less. In preferred embodiments, there are vaporizer and superheat sections in the combustion preheat section. Preferably, there is a staggered catalyst in the combustion chamber

The invention also includes the prebonded assembly having the structure used to form a laminated device having the structure of the compact steam reformer described herein. Further, the invention includes a method of making a compact steam reformer comprising assembling the components of the prebonded assembly and bonding the assembly. The invention further includes methods of making prebonded assemblies and/or bonded articles for the components and integrated steam reformer described herein, for example, by stacking plates. The component assemblies can be bonded separately or stacked with component assemblies and bonded together. "Bonding" can be any method to adhere plates together to form a device that essentially does not leak during operation. In some preferred embodiments, diffusion bonding is used to seal together a subassembly or entire device. In some preferred embodiments, a combination of bonding methods are used, such as diffusion bonding, welding, and/or brazing.

In another aspect, the invention provides a compact steam reformer system, comprising: the compact steam reformer as described herein and including reactants and products flowing through the steam reformer. The system may, optionally, also be characterized by conditions or measurements of system outputs.

The invention also includes a method of producing H_2 comprising passing CO and H_2O into the above-described compact steam reformer.

In another aspect, the invention provides apparatus for integrated combustion (or, more broadly, for integrated thermal reactions with heat transfer), comprising: a combustion chamber (or, more broadly, a first reaction chamber) having a width, length and height; an endothermic reaction chamber (or, more broadly, a second reaction chamber) disposed adjacent to the combustion chamber; wherein the height of the combustion chamber is 10 mm or less; an endothermic reaction chamber that is adjacent to the combustion chamber; wherein the combustion chamber length is defined in the direction of flow through the combustion chamber, and begins at a point where flow first encounters catalyst and ends where flow last encounters the catalyst; wherein height is in the direction of heat transfer from the combustion chamber to the endothermic reaction chamber; and wherein a combustion catalyst is staggered over the width of the combustion chamber, such that, at the beginning of the combustion chamber's length, catalyst is present in no more than 70% of the combustion chamber's width. In some preferred embodiments: the height and width of the combustion channel are substantially constant over entire length of combustion chamber; the apparatus is a laminated assembly; combustion catalyst extends over entire width of combustion chamber; ribs are disposed between catalyst sections; catalyst is flow-through; catalyst is flow-by; the flow resistance of each section is essentially the same as a function of width; each section is same length; catalyst is wall-coating or an insert; the staggered catalyst comprises at least 3 sections of catalyst each having equal length and width; and, the combustion catalyst comprises porous catalysts of different porosity, thickness, and/or length resulting in pressure drop differences for their respective areas.

The invention also provides a method of conducting integrated combustion (or, more broadly, integrated thermal reac-